New Chemical Attractants for Trapping *Lacanobia subjuncta*, *Mamestra configurata*, and *Xestia c-nigrum* (Lepidoptera: Noctuidae)

PETER J. LANDOLT

USDA–ARS, 5230 Konnowac Pass Road, Wapato, WA 98951

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ABSTRACT Significant numbers of 3 pest species of noctuid moths were captured in traps baited with acetic acid, 3-methyl-1-butanol, and 3-methyl-1-pentanol. These were *Lacanobia subjuncta* (Grote & Robinson); *Mamestra configurata* Walker, bertha armyworm; and *Xestia c-nigrum* (L.), spotted cutworm. The combination of acetic acid and 3-methyl-1-butanol was superior to the individual chemicals in attracting all 3 species, whereas the combination of acetic acid and 3-methyl-1-pentanol was superior to the individual chemicals in attracting *X. c-nigrum.* For the 3 species of moths, numbers captured were similar in traps baited with the combination of acetic acid and 3-methyl-1-butanol or acetic acid and 3-methyl-1-pentanol. Traps baited with these attractants captured both males and females at a ratio near 1:1.

KEY WORDS *Lacanobia subjuncta, Mamestra configurata, Xestia c-nigrum,* attractant, trapping

ADULTS OF MANY species of Lepidoptera are attracted to and feed on sugar-rich food sources, including floral nectaries, plant extrafloral nectaries, fermenting fruit, plant saps, and homopteran honeydew (Norris 1935). Insect collectors have long used fermented concoctions of sugars, fruit, beer, and yeast to make baits for attracting moths and butterflies (Holland 1903, Sargent 1976). Fermented solutions of molasses and similar sweet materials have been tested as baits for pest species of moth, including oriental fruit moth, *Cydia molesta* Busck (Frost 1926); corn earworm, *Helicoverpa zea* (Boddie) (Ditman and Cory 1933); tobacco budworm moths, *Heliothis virescens* (F.) (Landolt and Mitchell 1997); and grass loopers, *Mocis latipes* Guenee (Landolt 1995), among others. The identification of attractive odorants from these baits may provide useful lures for monitoring and controlling pest species.

A combination of compounds isolated and identified from fermented solutions of molasses (unpublished data) was found to be attractive to pestiferous yellowjackets (Landolt 1998a). Acetic acid in combination with isobutanol (2-methyl-1-propanol) comprises a potent lure for the western and German yellowjackets, *Vespula pensylvanica* (Saussure) and *Vespula germanica* F., respectively. In a study of the relationship between structures of similar short-chain alcohols and their attractiveness to wasps (Landolt 2000), it was noted that traps baited with 3-methyl-1-butanol and acetic acid or 3-methyl-1-pentanol and acetic acid captured large numbers of noctuid moths.

Subsequently, studies were conducted to determine if this combination of chemicals is attractive to 3 species of Noctuidae that are pests in the Yakima Valley of Washington—the bertha armyworm, *Mamestra configurata* Walker; the spotted cutworm, *Xestia c-nigrum* (L.); and *Lacanobia subjuncta* (Grote & Robinson). The bertha armyworm occurs on many diverse crops and is a major pest of mustards and canola (Mason et al. 1998). The spotted cutworm is a general feeder on many vegetable and other crops (Howell 1979). *L. subjuncta* recently has been recognized as a significant pest of apple in the Pacific Northwest (Landolt 1998b). Reported here are results of tests demonstrating the attractiveness of acetic acid and 3-methyl-1-butanol, as well as acetic acid and 3-methyl-1-pentanol to these insects. Also reported are the effects of altering amounts of blend components on attractiveness, and some measure of the attractiveness of the blend composed of acetic acid and 3-methyl-1-butanol in comparison with fermented molasses solutions.

Materials and Methods

The Trappit dome trap (Agrisense, Fresno, CA) was used in all tests. This trap design includes a reservoir for holding liquid baits, with a yellow bottom and clear top. Insect entry is through an opening in the bottom of the trap. A drowning solution was used in the reservoir of all traps. This solution was 200 ml water, 25 μl of detergent, 50 μl yellow, 25 μl blue, and 60 μl red food dyes (McCormick, Hunt Valley, NJ), and 20 mg clay per trap, as described in Landolt (1998a). The food dyes and clay were initially intended to produce a liquid close in appearance to the molasses solutions used for comparison. Detergent was added to cause more rapid submersion and drowning of trapped insects. Acetic acid (glacial, Baker Chemical, Phillipsburg, NJ), when tested as an attractant, was added to the drowning solution as a percentage of the water. 3-Methyl-1-butanol and 3-methyl-1-pentanol (Aldrich, Milwaukee, WI) were loaded in polyethylene caps (No. 60975 d-3, Kimball Glass, Vineland, NJ). Caps are hollow and are loaded by removing and replacing an inset in the cap top. Loaded caps were then impaled on a push pin glued to the inside of the top of the trap. It is assumed that release of the chemicals from polyethylene caps is primarily by diffusion through the cap walls, although contribution from leakage around the push pin is not ruled out. Traps were serviced 2 times per week, and the drowning solution with or without acetic acid was replaced weekly. Polyethylene caps containing alcohols were replaced monthly.

All experiments were conducted in commercial apple and pear orchards in Yakima County, WA. Traps were hung from tree branches at 1.5–2 m above ground, with 10 m between traps within a treatment block and a minimum of 10 m between adjacent treatment blocks. Experiments were conducted between 26 April and 16 September 1998. Concurrent season-long sampling of *L. subjuncta* adults using traps baited with female sex pheromone (Landolt and Smithhisler 1998) indicated 2 principal periods of male moth activity, roughly from late April into early June and from early August into early September, although male moths were generally present in the area continuously from April to October (Landolt et al. 1999). Voucher specimens of *L. subjuncta*, *M. configurata*, and *X. c-nigrum* are deposited in the M. T. James Entomological Museum, Washington State University, Pullman.

Four trapping experiments were conducted in apple orchards in the Yakima Valley during the summer of 1998. An initial experiment compared captures of pest moths in traps baited with the combination of acetic acid and 3-methyl-1-butanol to acetic acid alone and to fermented molasses solution. The 2nd experiment was a comparison of the attractiveness of the combination of acetic acid and 3-methyl-1-butanol with varying percentages of acetic acid in the drowning solution. The 3rd experiment was a comparison of the attractiveness of the combination of acetic acid and 3-methyl-1-butanol with varying amounts of 3-methyl-1-butanol in the polyethylene cap. The 4th experiment was a test of possible enhancement of attractiveness with the combination of acetic acid and 3-methyl-1-butanol or acetic acid and 3-methyl-1-pentanol, and a comparison of the attractiveness of the 2 alcohols. For all trapping experiments, a randomized complete block experimental design was used, with all treatments represented within each of 4 blocks.

Experiment 1. Traps were baited as follows: (1) 0.25% acetic acid in the drowning solution, (2) 0.25% acetic acid in the drowning solution and 1 ml of 3-methyl-1-butanol in a polyethylene cap, or (3) 200 ml of a 10% by volume solution of molasses (Grandma's Molasses, unsulfured, Motts, Stamford CT) in water. Traps were maintained through May and June and again through all of August. Data were analyzed as biweekly trap catch totals.

Experiment 2. Traps were baited with 1 ml of 3-methyl-1-butanol in a polyethylene cap and with either no acetic acid in the drowning solution or with 0.008, 0.03, 0.125, 0.5, or 2% acetic acid by volume in the 200 ml of drowning solution. This experiment was maintained through August and early September. Data were analyzed as weekly trap totals.

Experiment 3. Traps were all baited with 0.25% acetic acid in the drowning solution and either 0, 12.5, 25, 50, or 100% 3-methyl-1-butanol in 1 ml of a mixture of 3-methyl-1-butanol and mineral oil in a polyethylene cap. This experiment was set up in late July and was maintained through early September. Data were analyzed as weekly trap catch totals.

Experiment 4. Traps were either unbaited (control) or were baited with 0.25% acetic acid in the drowning solution (acetic acid), with 0.25% acetic acid in the drowning solution and 1 ml of 3-methyl-1-butanol in a polyethylene cap, with 0.25% acetic acid in the drowning solution and 1 ml of 3-methyl-1-pentanol in a polyethylene cap, with 1 ml of 3-methyl-1-butanol in a cap, or with 1 ml of 3-methyl-1-pentanol in a cap. This experiment was deployed 1 August and was maintained until 2 September. Data were analyzed as weekly trap catch totals.

Data were not included for some weeks in between flights when no moths were captured in any of the traps of an entire experiment. Treatment means were separated using the Wilcoxon signed rank test for experiments 1 and 4. Linear regression was used to analyze trap data from the 2nd and 3rd experiments to determine if there was a significant relationship between concentration of acetic acid in water or 3-methyl-1-butanol in mineral oil in a cap and captures of moths in traps. In the 3rd and 4th experiments, data for each concentration of attractant tested also were compared with the control (0% concentration of acetic acid and 3-methyl-1-butanol, respectively) by the Student *t*-test. For the 2nd, 3rd, and 4th experiments, data for males and females were combined.

Results

Experiment 1. Numbers of males and numbers of females of *L. subjuncta* captured in traps baited with acetic acid and 3-methyl-1-butanol were significantly greater than numbers of males or females captured in traps baited with acetic acid ($z = 6.66$, $P < 10^{-6}$, $n = 130$ for females; $z = 5.61$, $P < 10^{-6}$, $n = 130$ for males) or in traps baited with molasses ($z = 5.0$, $P = 0.00046$, $n = 130$ for females; $z = 4.81$, $P = 0.00002$, $n = 130$ for males) (Fig. 1A). Numbers of male and female *L. subjuncta* captured in traps baited with molasses were significantly greater than those captured in traps baited with acetic acid ($z = 3.51$, $P = 0.0004$, $n = 130$ for females; $z = 2.37$, $P = 0.18$, $n = 130$ for males). Totals of 323 female and 292 male *L. subjuncta* were captured in this experiment.

Numbers of males and numbers of females of *M. configurata* captured in traps baited with acetic acid and 3-methyl-1-butanol were significantly greater than numbers captured in traps baited with acetic acid ($z = 5.78$, $P < 10^{-6}$, $n = 115$ for females, $z = 4.51$, $P =$ 6 by 10^{-6}, $n = 115$ for males) or with molasses ($z = 4.75$, $P = 2 \times 10^{-5}$, $n = 115$ for females, $z = 5.07$, $P < 10^{-6}$, $n = 115$ for males) (Fig. 1B). There were no

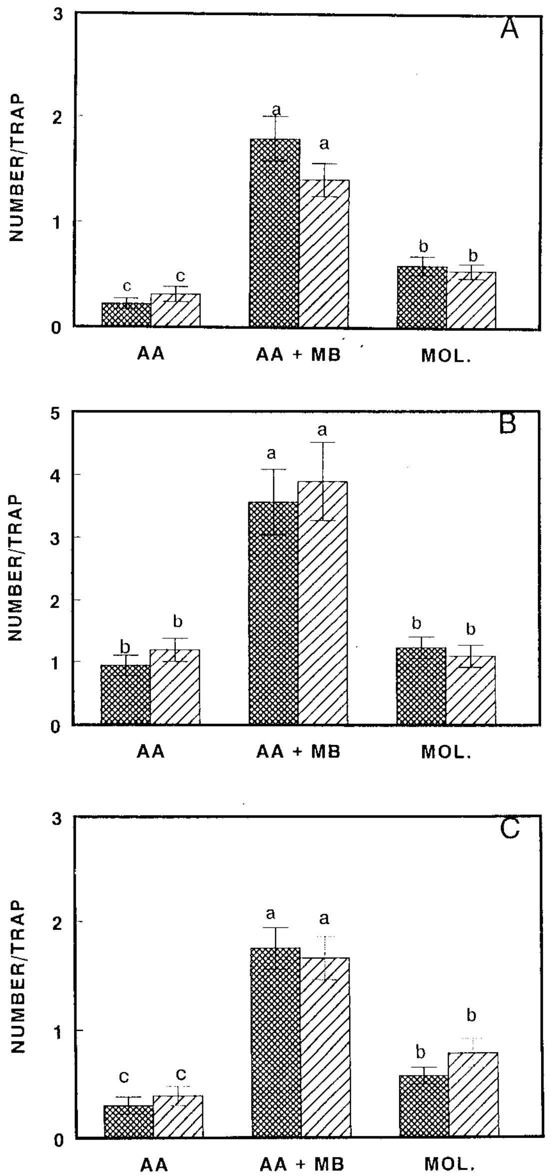

Fig. 1. Mean ± SEM numbers of *L. subjuncta* (A), *M. configurata* (B), and *X. c-nigrum* (C) moths captured weekly in traps baited either with acetic acid alone (AA), with the combination of acetic acid and 3-methyl-1-butanol (AAMB), or with fermented 10% molasses solution (MOL). Cross-hatched bars are for females captured, slashed bars are for males captured. Bars for the same species and same sex with the same letter are not significantly different by the Wilcoxon signed rank test at df = 130, $P \leq 0.05$ for *L. subjuncta,* 115 for *M. configurata,* and 125 for *X. c-nigrum.*

differences between catches of male or female *M. configurata* in traps baited with acetic acid compared with traps baited with molasses ($z = 1.30, P = 0.19, n = 115$ for females, $z = 0.82, P = 0.41, n = 115$ for males). Totals of 658 female and 708 *male M. configurata* were captured in this experiment.

Table 1. Mean numbers of moths captured per trap per week, in traps baited with 1 ml of 3-methyl-1-butanol in a polyethylene cap and acetic acid at different concentrations in the drowning solution

% acetic acid	*L. subjuncta*	*M. configurata*
0.0	0.03 ± 0.02	0.00 ± 0.00
0.008	0.08 ± 0.04	0.03 ± 0.03
0.03	0.28 ± 0.11*	0.30 ± 0.10*
0.125	0.40 ± 0.13*	0.68 ± 0.20*
0.5	0.40 ± 0.12*	0.38 ± 0.13*
2.0	0.45 ± 0.23	0.30 ± 0.11*

*, A significant difference from the control (0.0%) by a paired *t* test at $P < 0.05$.

Numbers of males and numbers of females of *X. c-nigrum* captured in traps baited with acetic acid and 3-methyl-1-butanol were significantly greater than numbers captured in traps baited with acetic acid ($z = 6.81, P < 10^{-6}, n = 125$ for females; $z = 5.74, P < 10^{-6}, n = 125$ for males) or with molasses ($z = 5.50, P < 10^{-6}, n = 125$ for females; $z = 4.03, P = 5.5 \times 10^{-5}, n = 125$ for males) (Fig. 1C). Also, numbers of both sexes captured in traps baited with molasses were significantly greater than in traps baited with acetic acid ($z = 2.85, P = 0.0044, n = 125$ for females; $z = 2.57, P = 0.01, n = 125$ for males). Totals of 328 female and 349 male *X. c-nigrum* were captured in this experiment.

Experiment 2. Numbers of moths captured in traps were suitable for statistical analyses for *L. subjuncta* and *M. configurata. Xestia c-nigrum* moths were not abundant during the time period of the experiment. There was a significant relationship by linear regression analysis between acetic acid concentration and catches of *L. subjuncta* moths in traps ($r^2 = 0.02$, df = 239, $P = 0.05$). However, numbers of *M. configurata* moths captured were not significantly related to the concentration of acetic acid tested over the concentration range of 0.008–2% ($r^2 = 0.002$, df = 239, $P = 0.5$).

Numbers of *L. subjuncta* captured in traps baited with the combination of acetic acid and 3-methyl-1-butanol were significantly greater than the numbers captured in traps baited with 3-methyl-1-butanol for the 0.03% ($t = 2.24$, df = 39, $P = 0.03$), 0.125% ($t = 2.73$, df = 39, $P = 0.009$), and 0.5% ($t = 3.06$, df = 39, $P = 0.004$) concentrations of acetic acid in water (Table 1). Numbers of *L. subjuncta* moths trapped were not significantly greater at the 0.008% ($t = 1.00$, df = 39, $P = 0.32$) and 2% ($t = 1.86$, df = 39, $P = 0.07$) concentrations of acetic acid. Numbers of *M. configurata* captured in traps baited with the combination of acetic acid and 3-methyl-1-butanol were significantly greater than the numbers captured in traps baited with 3-methyl-1-butanol for the 0.03% ($t = 2.93$, df = 39, $P = 0.006$, 0.125% ($t = 3.42$, df = 39, $P = 0.001$), 0.5% ($t = 2.94$, df = 39, $P = 0.006$), and 2% ($t = 2.76$, df = 39, $P = 0.009$) concentrations of acetic acid. Numbers of *M. configurata* were not significantly greater at the 0.008% ($t = 1.0$, df = 39, $P = 0.3$) concentration of acetic acid. Totals of 37 female and 26 male *L. subjuncta* and 32 female and 39 male *M. configurata* were captured in this experiment.

Table 2. Mean numbers of moths captured per trap per week, in traps baited with 0.25% acetic acid in the drowning solution and different concentrations of 3-methyl-1-butanol in mineral oil in a polyethylene cap

% 3-methyl-1-butanol in oil in cap	*L. subjuncta*	*M. configurata*
0.0	0.02 ± 0.02	0.18 ± 0.07
12.5	0.49 ± 0.10*	0.71 ± 0.18*
25	0.64 ± 0.12*	0.93 ± 0.19*
50	0.67 ± 0.15*	0.91 ± 0.22*
100	0.62 ± 0.15*	1.00 ± 0.19*

*, Significantly greater than the control (0%) by Student *t* test at $P < 0.05$.

Experiment 3. Numbers of moths captured in traps were sufficient for statistical analyses for *L. subjuncta* and *M. configurata. Xestia c-nigrum* moths were not abundant during the time of the experiment. Numbers of *L. subjuncta* and *M. configurata* moths captured in traps baited with the combination of acetic acid and 3-methyl-1-butanol increased with increasing amounts of 3-methyl-1-butanol (Table 2). Linear regression analysis showed a significant relationship between numbers of moths trapped versus the percentage of 3-methyl-1-butanol in a 3-methyl-1-butanol-mineral oil mixture in the cap, for both *L. subjuncta* ($r^2 = 0.03$, $F = 7.33$, df = 224, $P = 0.007$) and *M. configurata* ($r^2 = 0.03$, $F = 7.07$, df = 224, $P = 0.008$).

At each amount of 3-methyl-1-butanol evaluated, numbers of both species of moths in traps were significantly greater than numbers in traps baited with acetic acid alone by the Student *t*-test. For *L. subjuncta,* trap catches were greater for the 12.5% ($t = 4.5$, df = 44, $P = 4.78 \times 10^{-5}$), 25% ($t = 4.7$, df = 44, $P = 2.9 \times 10^{-5}$), 50% ($t = 4.3$, df = 44, $P = 9.1 \times 10^{-5}$), and 100% ($t = 3.9$, df = 44, $P = 0.0003$) 3-methyl-1-butanol in mineral oil in the cap. For *M. configurata,* trap catches were greater for the 12.5% ($t = 2.73$, df = 44, $P = 0.009$), 25% ($t = 4.01$, df = 44, $P = 0.0002$), 50% ($t = 3.62$, df = 44, $P = 0.0007$), and 100% ($t = 4.12$, df = 44, $P = 0.0002$) 3-methyl-1-butanol in mineral oil in the cap. However, for both species, numbers of moths captured in traps were similar for acetic acid and 3-methyl-1-butanol at 12.5, 25, 50, and 100% in the cap. Totals of 66 female and 41 male *L. subjuncta* and 108 female and 65 male *M. configurata* were captured in this experiment.

Experiment 4. Numbers of *L. subjuncta* captured were highest in traps baited either with the combination of acetic acid and 3-methyl-1-butanol or with the combination of acetic acid and 3-methyl-1-pentanol (Fig. 2A), although numbers captured in traps baited with acetic acid and 3-methyl-1-butanol were not significantly higher than those in traps baited with 3-methyl-1-pentanol alone. Numbers of *L. subjuncta* captured in traps baited with 3-methyl-1-butanol or with 3-methyl-1-pentanol or with acetic acid alone were similar, although significantly higher than the unbaited traps. Totals of 82 females and 86 male *L. subjuncta* were captured in this experiment.

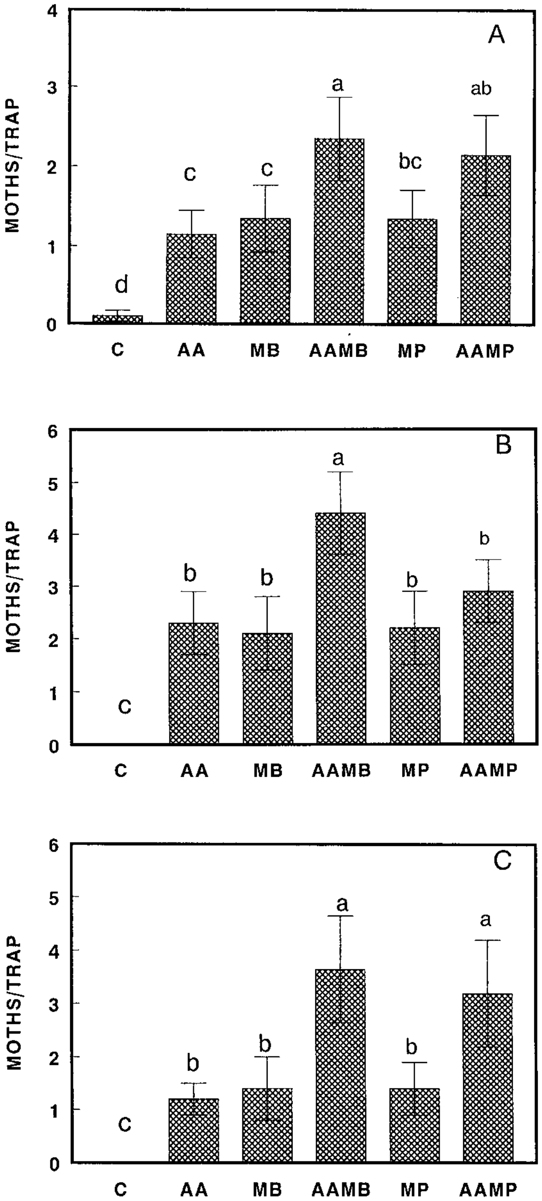

Fig. 2. Mean ± SEM numbers of *L. subjuncta* (A), (*M. configurata*) (B), and *X. c-nigrum* (C) captured weekly in unbaited traps (C) or in traps baited with 0.25% acetic acid (AA) in the drowning solution, with 1 ml of 3-methyl-1-butanol (MB) or 1 ml of 3-methyl-1-pentanol (MP) or combinations of acetic acid and either of the alcohols (AAMB and AAMP). Bars that are capped with the same letter are not significantly different by the Wilcoxon signed rank test at df = 19, $P \leq 0.05$.

Numbers of *M. configurata* captured were highest in traps baited with the combination of acetic acid and 3-methyl-1-butanol (Fig. 2B). Numbers of *M. configurata* captured in traps baited with 3-methyl-1-butanol, 3-methyl-1-pentanol, 3-methyl-1-pentanol with acetic acid, or acetic acid alone were similar, although significantly higher than the unbaited traps. Totals of 141 female and 134 male *M. configurata* were captured in this experiment.

Numbers of *X. c-nigrum* captured were highest in traps baited either with the combination of acetic acid and 3-methyl-1-butanol or with the combination of acetic acid and 3-methyl-1-pentanol (Fig. 2C). Numbers of *X. c-nigrum* captured in traps baited with 3-methyl-1-butanol or with 3-methyl-1-pentanol or with acetic acid alone were similar, although significantly higher than in unbaited traps. Totals of 100 female and 112 male *X. c-nigrum* were captured in this experiment.

Discussion

The results of these tests clearly demonstrate enhanced attraction of *L. subjuncta, M. configurata,* and *X. c-nigrum* to the combination of acetic acid and 3-methyl-1-butanol, compared with acetic acid alone and to 3-methyl-1-butanol alone. In addition, the attraction of *X. c-nigrum* moths to the combination of acetic acid and 3-methyl-1-pentanol was enhanced compared with the individual chemicals. In the 1st experiment, the superiority of the attractant blend (acetic acid and 3-methyl-1-butanol) in comparison with acetic acid by itself and with fermented molasses solution was apparent. In the 2nd experiment, the increased attractiveness of the same blend to *L. subjuncta* and *M. configurata* in comparison with 3-methyl-1-butanol alone was demonstrated and in the 3rd experiment the increased attractiveness of the same blend with *L. subjuncta* and *M. configurata* compared with acetic acid alone was again demonstrated. The greater activity of the combination of chemicals versus the individual components was again demonstrated in the 4th experiment as was the increased attractiveness of the combination of acetic acid and 3-methyl-1-pentanol in comparison with acetic acid alone or 3-methyl-1-pentanol alone to the spotted cutworm. It seems likely that *L. subjuncta* also responds significantly to the combination of acetic acid and 3-methyl-1-pentanol, but additional testing is required to determine if that is the case.

This is the first chemical attractant available for use in trapping females of these species. In the 1st experiment, it was evident that both sexes respond similarly to these blends. Throughout the experiments, which lasted throughout the 1998 field season and through both generations of both species of moths, these chemicals consistently attracted females as well as males of *L. subjuncta* and *M. configurata.* Female-produced sex pheromones have been identified that are attractive to males of *M. configurata* (Chisholm et al. 1975), *X. c-nigrum* (Steck et al. 1982), and *L. subjuncta* (Landolt and Smithhisler 1998). Additional experimentation is necessary to determine if the combination of acetic acid and 3-methyl-1-butanol will be useful in lures for monitoring male or female moths of these species, or in toxic bait formulations to be used for pest population control (e.g., Charmillot and Hofer 1997, Villavaso et al. 1998).

There was not a significant linear relationship between concentrations of acetic acid and numbers of *M. configurata* captured, and the relationship between acetic acid concentrations and captures of *L. subjuncta* in traps was weak, although significant. Similar results were obtained in tests comparing different concentrations of acetic acid as part of an attractive blend for social wasps (Landolt et al. 1998a). One possibility is that the higher concentrations of acetic acid in air at the trap entrance may become repellent and that an optimum amount of acetic acid may be released from the drowning solution at 0.125% acetic acid. Another concern is that increasing the amount of one compound (acetic acid) independent of the other (3-methyl-1-butanol) will alter the release ratio of the chemicals, possibly adversely affecting the attractiveness of the blend. The results of the 3rd experiment, altering the amount of 3-methyl-1-butanol, indicate that we may not have tested a broad enough range of release rates to find an optimum. Additional testing will be necessary to more accurately determine the nature of the relationships between both the amounts and the ratios of the attractive chemicals and the moth responses.

The attractiveness of these blends of chemicals to moths, particularly the combination of acetic acid and 3-methyl-1-butanol, is likely based on the orientation of moths to fermented sugar-rich materials on which they feed. Although our original studies of headspace volatiles from fermented molasses indicated the presence of acetic acid and isobutanol (unpublished), among many other compounds, 3-methyl-1-butanol also is indicated as a byproduct of microbial activities. It has been found in odors produced by bacteria (DeMilo et al. 1996) and in headspace of a fermented corn extractive (Lee et al. 1997).

It is likely that this combination of chemicals is attractive to additional pest species of Lepidoptera. Noctuids generally appear to be attracted to fermented molasses or other sugar baits (Frost 1928) although little has been done to document which species have been trapped. The response here of 3 pest species in 2 taxonomic subfamilies indicates the possibility of a general response of many Noctuidae to these compounds. Furthermore, in these experiments, numerous nonpest species of Noctuidae were captured in traps and were not tallied or identified to species. Additional experiments will be needed to determine if other pest species are attracted to the combinations of acetic acid and 3-methyl-1-butanol or acetic acid and 3-methyl-1-pentanol.

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